Guidance on best available techniques and best environmental practices

Waste Incineration Facilities

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Waste incineration facilities

**SUMMARY**

Waste incineration facilities are identified in the Minamata Convention as one of the major industrial sources of mercury emissions. The category is listed in its Annex D.

The potential purposes of waste incineration include volume reduction, energy recovery, destruction or at least minimization of hazardous constituents, disinfection and the recovery of some residues.

To achieve best results for environmental protection as a whole, it is essential to coordinate the waste incineration process with upstream activities (e.g., waste management techniques) and downstream activities (e.g., disposal of solid residues from waste incineration).

When considering proposals to construct new waste incinerators, consideration should be given to alternatives such as activities to minimize the generation of waste, including resource recovery, reuse, recycling, and waste separation, and the promotion of products that contribute less or no mercury to waste streams. Consideration should also be given to approaches that prevent mercury entering waste which will be incinerated.

The environmentally sound design and operation of waste incinerators require the use of both best available techniques (BAT) and best environmental practices (BEP), which are to some extent overlapping, in order to prevent or minimize the emissions of harmful substances like mercury.

BEP for waste incineration include appropriate off-site procedures, such as overall waste management and consideration of the environmental impacts of siting, and on-site procedures, such as waste inspection, proper waste handling, incinerator operation, management practices and the handling of residues.

BAT for waste incineration include the appropriate site selection, waste input and control, and techniques for combustion, flue gas, solid residue and effluent treatment. BAT for controlling mercury emissions from waste incineration facilities may be considered to be high efficiency scrubbers with ingredients in the scrubber liquor; scrubber with injection of bromine containing chemicals into the combustion chamber; or activated carbon injection with FF. In the event of high mercury levels in the raw gas, a combination of the above techniques can be applied.

Releases of mercury from municipal solid waste incinerators designed and operated according with BAT and BEP considerations in mind occur mainly via fly ash, bottom ash and filter cake from wastewater treatment. Accordingly, it is of major importance to provide for a safe sink of these waste types, for example, through their pretreatment and final disposal in dedicated landfills, which are designed and operated according to BAT.

With a suitable combination of primary and secondary measures mentioned in this chapter, mercury emissions into the air not higher than 1–10 µg/m3 (at 11 per cent O2) are associated with BAT. It is further noted that, under normal operating conditions, emissions lower than this level can be achieved with a well-designed waste incineration plant.

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# Introduction

This section is concerned only with the dedicated incineration of wastes and not other situations where waste is thermally treated, for example, co-incineration processes such as cement kilns and large combustion plants, which are dealt with in the sections relating to those processes.

Open burning is the burning of any type of waste in the open air or in open dumps, and in incineration devices range from so-called “drum incinerators” and locally constructed incinerators with no pollution control to small ovens used for the burning of medical waste that do not allow for complete combustion. Open burning of waste mercury and mercury-added products contributes significantly to releases of mercury from products.

Accordingly, open burning is considered “bad environmental practice” and should be discouraged as it can lead to emissions of toxic substances into the environment. The practices of open burning and burning in simply constructed incineration devices are not covered further in this guidance.

Mercury is volatized in the incineration process and, therefore, specific action should be taken both before, during and after incineration to reduce these emissions. The only relevant primary techniques for preventing emissions of mercury into the air before incinerating are those that prevent or control, if possible, the inclusion of mercury in waste.

For existing incinerators, parties shall implement one or more of the measures listed in paragraph 5 of Article 8 of the Convention. The party may apply the same measures to all relevant existing sources, or may adopt different measures in respect of different source categories. The objective for the measures applied by a party shall be to achieve reasonable progress in reducing emissions over time. This can include the use of best available techniques and best environmental practices, a multi-pollutant control strategy that would deliver co-benefits for control emissions or other possible measures, the objective being to achieve reasonable progress in reducing emissions over time.

For new incinerators, however, where construction or substantial modification starts at least one year after the date of the Convention’s entry into force for the party, parties shall be required to use best available techniques and best environmental practice to control and, where feasible, reduce emissions.

1. **Processes used in waste incineration facilities, including consideration of input materials and behaviour of mercury in the process**
	1. **General description of wastes that could result in emissions of mercury or mercury compounds when incinerated**
		1. **Waste hierarchy**

The hierarchy captures the progression of a material or product through successive stages of waste management, and represents the latter part of the life-cycle for each product. The primary aim of the waste hierarchy is to extract the maximum practical benefits from materials and to generate the minimum amount of waste. The proper application of the waste hierarchy can have several benefits: it can help prevent emissions of mercury from waste materials that may contain mercury or are contaminated with mercury, reduce greenhouse gas production, reduce other air pollutants, save energy, conserve resources, create jobs and stimulate the development of green technologies. The waste hierarchy is divided into the following stages:

* **Prevention**: The prevention of waste is the most vital point in the waste hierarchy. Prevention or reduction minimizes the generation of waste products in the first place. Prevention usually results in the lowest environmental and economic life-cycle costs because it does not require collecting or processing of materials. Typically, prevention also produces significant benefits in terms of production efficiencies and the use of resources. It involves using less material in design and manufacture, trying to keep products for longer, and using less hazardous materials.
* **Reuse**: The direct reuse of alternative uses of materials from the waste stream is the next most desirable option. It is any operation where products or materials that are not waste are used again for the same purpose for which they were intended. Reusing materials from the waste stream often requires collection with relatively little or no processing. It involves checking, cleaning, repairing and refurbishing entire items or spare parts. Materials contaminated with mercury should not be reused.
* **Recycle**: [Recycling](http://en.wikipedia.org/wiki/Recycling) of waste is the next priority. It applies to any activity that includes the collection of used, reused, or unused items that would otherwise be considered waste. Recycling involves sorting and processing the recyclable products into raw material and then remanufacturing the recycled raw materials into new products.
* **Recovery**: The recovery of waste is further separated into categories: the recovery of materials and the recovery of energy. The preferred option is that which is better for the environment and human health. The recovery of materials is most often preferred and includes activities such as recycling and composting. These management activities generally require a collection system and a method of material processing and conversion into a new product. Recovery of energy, such as [incineration](http://en.wikipedia.org/wiki/Incineration), is usually the less popular option. The conversion of non-recyclable waste materials into usable heat, electricity, or fuel is accomplished through a variety of processes, including anaerobic digestion, gasification and pyrolysis.
* **Disposal**: The last resort is disposal and this is only considered once all other possibilities have been explored. Disposal is any operation that involves the dumping and incineration of waste without energy recovery. Before final disposal, pretreatment may be necessary, depending on the nature of the waste. [Landfilling](http://en.wikipedia.org/wiki/Landfills) is the most common form of waste disposal and the final disposal option.
	+ 1. **Introduction to different types of waste with regard to mercury emissions from waste incinerator facilities**
			1. **Municipal waste**

Municipal solid waste, more commonly known as trash or garbage and sometimes abbreviated as MSW, consists of everyday items that are used and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, batteries and countless others. These come from households, schools, hospitals, businesses and other establishments. The municipal solid waste industry can be divided into four components, namely: [recycling](http://en.wikipedia.org/wiki/Recycling), [composting](http://en.wikipedia.org/wiki/Compost), [landfilling](http://en.wikipedia.org/wiki/Landfill), and [waste-to-energy](http://en.wikipedia.org/wiki/Waste-to-energy) via incineration. The primary steps in the waste cycle are generation, collection, sorting and separation, transfer, and disposal. A number of municipal wastes contain hazardous substances, along with organic chemicals such as pesticides. Traditional medicines, cosmetics and other items may also contain hazardous substances.

The sources of mercury in municipal solid waste include the following: household batteries, electric lighting, paint residues, thermometers, thermostats, pigments, dental uses, special paper coating, mercury light switches, film pack batteries and others. Typical mercury concentrations in municipal solid waste range from 0.15 to 2 mg/kg (Muenhor et al. 2009).

* + - 1. **Hazardous waste**

Hazardous waste is a waste that has the potential to adversely affect human health and the environment, and therefore must be managed in an environmentally sound manner. Hazardous wastes can be liquids, solids, gases, or sludges. They can be discarded in commercial products, such as cleaning fluids or pesticides, or the by-products of manufacturing processes. Chapter II of the Technical Guidelines of the Basel Convention can provide further guidance and information on wastes considered hazardous, in addition to the scope of mercury waste covered under that Convention (Basel Convention, 2015).

* + - 1. **Waste from electrical and electronic equipment**

Electrical and electronic equipment may contain mercury along with other materials that are hazardous. Often, electrical and electronic waste is collected separately, and is not usually incinerated but is the subject of recovery and recycling processes – these processes to recover materials are not the subject of this guidance. Electrical and electronic equipment may be collected together with municipal waste. Such equipment, if known to contain mercury and entering the waste stream, should be dealt with in accordance with Article 11 of the Minamata Convention. Sometimes, however, electrical and electronic equipment is incinerated along with municipal waste, and can contribute to mercury emissions.

* + - 1. **Medical waste containing mercury or contaminated with mercury**

Medical waste is generally defined as any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biological materials. The World Health Organization (WHO) classifies medical waste in the following categories: sharps, infectious, pathological, radioactive, pharmaceutical and others (often sanitary waste produced at hospitals) (WHO, 2014, p. 4). The specific categories in which medical waste is classified may vary in different countries (e.g., sharps are not classified as hazardous waste in all countries).As a general rule, between 75 and 90 per cent of the waste produced by health-care facilities is non-risk (non-infectious, non-hazardous) general waste, comparable to municipal waste. Only a small proportion of health-care waste is regarded as hazardous, and may create health risk (Emmanuel, 2012).

Hazardous medical waste has the possibility to affect humans in non-infectious ways. This type of waste includes sharps, which are generally defined as objects that can puncture or lacerate the skin, and can include needles and syringes, discarded surgical instruments such as scalpels and lancets, culture dishes and other glassware. Hazardous medical waste can also include chemicals. Some hazardous waste can also be considered infectious waste, depending on its usage and exposure to human or animal tissue prior to discard. Old pharmaceuticals are sometimes hazardous, and may contain mercury.

Mercury is used in a variety of ways specific to the medical sector, which include:

* Mercury in measuring devices: Mercury is contained in many common medical measuring devices such as sphygmomanometers (blood pressure devices), thermometers (specifically body temperature thermometers but also others) and a number of gastro-intestinal devices, such as cantor tubes, esophageal dilators (bougie tubes), feeding tubes and Miller Abbott tubes. As in other types of instruments, mercury has traditionally been used in these devices because of its unique physical properties, including the ability to provide highly precise measurements.
* Mercury in some types of traditional medicines: Some traditional medicines may contain mercury, although a number of regulatory authorities have introduced controls.
* Mercury in dental amalgams: Dental amalgam, sometimes referred to as “silver filling,” is a silver-coloured material used to fill teeth that have cavities. Dental amalgam is made of two nearly equal parts: liquid mercury and a powder containing silver, tin, copper, zinc and other metals. Amalgam has been one of the most commonly used tooth fillings. If the dental amalgam is incinerated, mercury may be emitted to the air from the incinerator stacks.
* Mercury compounds in certain preservatives, fixatives and reagents used in hospital: Some mercury compounds are used as preservatives in medicines and other products including vaccines.
	+ - 1. **Sewage sludge**

Sewage sludge is a direct by-product of the treatment of domestic sewage at a wastewater treatment facility. Dental amalgam can contribute to the mercury load of sewage sludge if the amalgam waste is put into the wastewater stream, rather than being separated out. Owing to the physical-chemical processes involved in the treatment, the sewage sludge tends to concentrate heavy metals such as mercury, cadmium, lead and others and poorly biodegradable trace organic compounds, together with potentially pathogenic organisms (viruses, bacteria, etc.) present in wastewater. Typical levels of mercury in sewage sludge range between 0.6 and 56 mg/kg dry sludge (Hisau; Lo, 1998). Concentrations ranging from 1 to 4 mg/kg dry matter have also been reported, however (Werther; Saenger 2000).

* + - 1. **Scrap wood**

Scrap wood is generated at residential and commercial wood frame construction sites, and may include such items as window frames painted with mercury-containing paint. Demolition operations usually generate wood waste which, as a result of its non-uniform nature, compounded by commingling with other materials, is not always reusable. If not contaminated with hazardous substances such as mercury (e.g., window frames painted with mercury-containing paint) the wood can still be reused, for example for wood panels. Contaminated wood may either be burned in an incineration plant or disposed of in a designated landfill site.

* + - 1. **Common industrial waste**

Sometimes industrial waste containing, or contaminated with mercury, e.g., paints, solvents, petrochemicals, spent activated carbon, is incinerated along with municipal waste and can contribute to emissions of mercury and other hazardous substances.

* 1. **Incineration process**
		1. **Introduction to general incineration technique**

Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether provides for the overall management of the broad range of wastes that arise in society. The objective of waste incineration is to treat wastes in such a manner as to reduce their volume and hazard, while capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also facilitate recovery of the energy, mineral or chemical content from waste.

Incinerators come in a variety of furnace types and sizes and combinations of pre-combustion and post-combustion treatment. There is also considerable overlap among the designs of choice for municipal solid waste, hazardous waste and sewage sludge incineration.

Incinerators are usually designed for full oxidative combustion over a general temperature range of 850 °C–1,200 °C. This may include temperatures at which calcinations and melting also occur. Gasification and pyrolysis represent alternative thermal treatments that restrict the amount of primary combustion air necessary to convert waste into process gas, which may be used as a chemical feedstock or incinerated with energy recovery. Compared to incineration, however, these systems are used relatively infrequently and operational difficulties have been reported at some installations. Waste incinerator installations may be characterized by the following functions: waste delivery, storage, pretreatment, incineration and energy recovery, flue gas cleaning, solid residue management, and wastewater treatment. The nature of the input waste will have a significant bearing on how each component is designed and operated.

Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water. During incineration, flue gases are created that will contain the majority of the available fuel energy as heat. In fully oxidative incineration the main constituents of the flue gas are water vapour, nitrogen, carbon dioxide and oxygen. Depending on the composition of the material incinerated, operating conditions and the flue gas cleaning system installed, acid gases (sulfur oxides, nitrogen oxides, hydrogen chloride), particulate matter (including particle-bound metals), and volatile metals, along with a wide range of volatile organic compounds, are emitted. Incineration of municipal solid waste and hazardous waste has also been shown to be a major potential emitter of mercury. Emissions can be substantially high when the input from possible sources (waste containing mercury, e.g., in products, treated waste wood) is not controlled or removed before incineration. It should be noted that mercury is present in elemental, oxidized and particulate forms in the flue gas. Mercury present in oxidized form – predominantly as mercury (II) chloride in incinerator flue gases – is generally easier to remove than elemental mercury.

Depending on the combustion temperatures during the main stages of incineration, volatile metals and inorganic compounds (e.g., salts) are totally or partly evaporated. These substances are transferred from the input waste to both the flue gas and the fly ash it contains. A residue fly ash (dust) and heavier solid ash (bottom ash) are created. The proportions of solid residue vary greatly according to the waste type and detailed process design. Other releases are residues from flue gas treatment and polishing, filter cake from wastewater treatment, salts and releases of substances into wastewater. It is therefore of major importance to provide for a safe sink of these waste types containing mercury. (see section 3.7). Figure 1 presents a simplified flow scheme of an incinerator.



**Figure 1 Simplified flow scheme of an incinerator**

* + 1. **Pretreatment of waste for incineration**

**Mixing of waste**

Techniques used for mixing may include:

* Mixing of liquid hazardous wastes to meet input requirements for the installation
* Mixing of wastes in a bunker using a grab or other machine

Mixing of waste may serve the purpose of improving feeding and combustion behaviour and can help to avoid high mercury concentrations in the burned waste. Mixing of hazardous waste clearly involves risks and the mixing of different waste types should be carried out according to a recipe. In bunkers, wastes are mixed using bunker cranes in the storage bunker itself. Crane operators can identify potentially problematic loads (e.g., baled wastes, discrete items that cannot be mixed or will cause loading and feeding problems) and ensure that these are removed, shredded or directly blended (as appropriate) with other wastes. It is difficult for the crane operators themselves to identify mercury-containing waste.

**Shredding of mixed municipal wastes**

Untreated mixed municipal waste can be roughly shredded by passing delivered waste through crocodile shears, shredders, mills, rotor shears or crushers. The homogeneity of the waste is improved by shredding, resulting in more even combustion and reduction and more stable emissions from the furnace. Ensuring that the raw gas composition is more even will enable closer optimization of the flue-gas cleaning process. Many wastes contain appreciable quantities of ferrous and non-ferrous metals. These can be an inherent part of the waste itself (e.g., food and drink containers in municipal solid waste) or arise from the packaging of waste in drums (e.g., hazardous wastes) or other metal containers.

When the incoming wastes are shredded, metals can be removed before incineration to allow recycling. Metal separation can be achieved by using:

* Over-band magnets for large ferrous materials, such as shredded drums;
* Drum magnets for small and heavy ferrous items such as batteries, nails, coins, etc.,
* Eddy current separators for non-ferrous metals – mainly copper and aluminium used for packaging and electrical components.

**Shredding of drummed and packaged hazardous wastes**

Liquid packaged waste and packed or bulk solid waste may be pretreated to produce a mixture for continuous feed to the furnace. Suitable wastes may be treated to a pumpable state for pumped injection to the kiln or shredded for adding to the storage burner, in process where solids and liquids separate and are then fed to the kiln separately using grabs and pumping respectively.

Pallets containing packaged liquid wastes of low to medium-high viscosity are shredded to between 5 and 10 cm. The shredded waste may then be screened before being transferred to tanks. Plastics that are screened out may be used as an energy source for incineration and ferrous metals can be removed for recycling with the use of magnets. In other cases wastes such as waste oils are not screened, and instead are pumped as a mixture of liquids and shredded solids to the kiln with thinning liquids (European Commission, 2006, Waste Incineration)

* + 1. **Description of incinerator types**

The following sections describe continuous incineration processes. It is acknowledged that batch incineration processes are sometimes used; these, however, are usually associated with high emissions during start-up and shutdown and are not considered further in this chapter.

* + - 1. **Rotary kiln incinerator**

For the incineration of hazardous waste which includes many types of medical waste rotary kilns are most commonly used (figure 2), but grate incinerators (including co-firing with other wastes) are also sometimes applied to solid wastes, and fluidized bed incinerators to some pretreated materials. Static furnaces are also widely applied at on-site facilities at chemical plants.



**Figure 2 Rotary kiln incineration system (**[**www.hitemptech.com**](http://www.hitemptech.com)**)**

Given the hazardous (and often uncertain) composition of the incoming waste streams, greater emphasis is placed on acceptance criteria, storage, handling and pretreatment than with municipal solid waste. For low-energy-value wastes, auxiliary fuels may be required.

In a rotary kiln solid, sludge, containerized or pumpable waste is introduced at the upper end of the inclined drum. Temperatures in the kiln usually range between 850 °C (500 °C when used as a gasifier) and 1,200 °C (as a high-temperature ash-melting kiln). The slow rotation of the drum allows a residence time of 30–90 minutes. The secondary combustion chamber following the kiln allows the oxidation of the combustion gases. Liquid wastes or auxiliary fuels may be injected here along with secondary air to maintain a minimum residence time of two seconds and temperatures in the range of 850 °C–1,100 °C, effectively breaking down most remaining organic compounds. Requirements for combustion conditions may be prescribed, as in European Union Directive 2010/75/EU on the incineration of waste. Rotary kilns and afterburning chambers are in most cases constructed as adiabatic, ceramic-lined combustion chambers. After the combustion chamber flue gases pass through a void zone until a temperature of about 700 °C is reached. Subsequently, heating bundles such as evaporators, super-heaters and feed water preheaters are arranged. The waste heat boiler and energy supply system is comparable to that of grate firing systems. Incinerator capacities range between 0.5 and 3 tons per hour (for health-care waste incineration).

* + - 1. **Liquid injection incinerators**

Liquid injection incinerators, like rotary kiln incinerators, are commonly used for hazardous waste incineration. Liquid injection incinerators can be used to dispose of virtually any combustible liquid or liquid-like waste (e.g., liquids, slurries, and sludges). Typical liquid injection incinerator systems, which are possibly the simplest type of combustion device, include a waste burner system, an auxiliary fuel system, an air supply system, a combustion chamber, and an air pollution control system, as illustrated in

3. Liquid wastes are fed and atomized into the combustion chamber through the waste burner nozzles. These nozzles atomize the waste and mix it with combustion air. Atomization is usually achieved either by mechanical methods such as a rotary cup or pressure atomization systems, or by twin-fluid nozzles which use high-pressure air or steam. With a relatively large surface area, the atomized particles vaporize quickly, forming a highly combustible mix of waste fumes and combustion air. Typical combustion chamber residence time and temperature ranges are between 0.5 and 2 seconds, and 700 °C and 1,600 °C, respectively, in order to ensure complete liquid waste combustion. Liquid waste feed rates can exceed 2,000 l/hr. If the energy content of the waste is not high enough to maintain adequate ignition and incineration temperatures, a supplemental fuel such as fuel oil or natural gas is provided. In some cases, wastes with high solids are filtered prior to incineration to avoid nozzle plugging (US EPA 2005).



**Figure 3 Typical liquid injection incinerator**



Grate incinerator

There are different types of grate incinerators, namely: moving and fixed grates.

*Moving grate incinerators*

The typical incineration plant for [municipal solid waste](http://en.wikipedia.org/wiki/Municipal_solid_waste) is a moving grate incinerator. Here the waste moves through the combustion chamber and this movement makes possible a more efficient and complete combustion.

The units can be designed with a range of capacities. One example is a single moving grate boiler which can handle up to 35 tons of waste per hour, and can operate for 8,000 hours per year with only one scheduled stop for inspection and maintenance of about one month’s duration. The waste is introduced by a [waste crane](http://en.wikipedia.org/wiki/Grab_%28tool%29) through the so-called “throat” at one end of the grate, from where it moves down over the descending grate to the ash pit in the other end. Here the ash is removed through a water lock. Part of the combustion air (primary combustion air) is supplied through the grate from below.

This air flow also has the purpose of cooling the grate itself. Cooling is important for the mechanical strength of the grate, and many moving grates are also water-cooled internally. Secondary combustion air is supplied into the boiler at high speed through nozzles over the grate. It facilitates complete combustion of the flue gases by introducing [turbulence](http://en.wikipedia.org/wiki/Turbulence) for better mixing and by ensuring a surplus of oxygen. In multiple or stepped hearth incinerators, the secondary combustion air is introduced in a separate chamber downstream the primary combustion chamber.

In European Union countries (European Commission, 2000), incineration plants must be designed to ensure that the [flue gases](http://en.wikipedia.org/wiki/Flue_gas) reach a temperature of at least 850 °C for two seconds in order to ensure proper breakdown of toxic organic substances. In order to comply with this requirement at all times, backup auxiliary burners (often fuelled by oil) must be installed, and these are fired into the boiler in the event that the [heating value](http://en.wikipedia.org/wiki/Heating_value) of the waste becomes too low to reach this temperature alone. The [flue gases](http://en.wikipedia.org/wiki/Flue_gas) are then cooled in the [super-heaters](http://en.wikipedia.org/wiki/Superheater), where the heat is transferred to steam, heating the steam typically to 400 °C at a pressure of 4,000 [kPa](http://en.wikipedia.org/wiki/Bar_%28unit%29) for the electricity generation in the [turbine](http://en.wikipedia.org/wiki/Turbine).

At this point, the flue gas is at around 200 °C and is passed to the [flue gas cleaning system](http://en.wikipedia.org/wiki/Incineration#Flue-gas_cleaning). Often, incineration plants consist of several separate boiler lines (boilers and flue gas treatment plants), so that waste can continue to be received at one boiler line while the others are undergoing maintenance, repair, or upgrading.

*Fixed grate*

The older and simpler kind of incinerator was a brick-lined cell with a fixed metal grate over a lower ash pit, with one opening in the top or side for loading and another opening in the side for removing incombustible solids, called clinker. Many small incinerators formerly found in apartment houses have now been replaced by [waste compactors](http://en.wikipedia.org/wiki/Compactor).

* + - 1. **Fluidized bed incinerator**

Fluidized bed incinerators are widely used for the incineration of finely divided wastes such as refuse-derived fuel and sewage sludge. The method has been used for decades, mainly for the combustion of homogeneous fuels. The fluidized bed incinerator is a lined combustion chamber in the form of a vertical cylinder. In the lower section, a bed of inert material (e.g., sand or ash) on a grate or distribution plate is fluidized with air. The waste for incineration is continuously fed into the fluidized sand bed from the top or side. Preheated air is introduced into the combustion chamber via openings in the bed plate, forming a fluidized bed with the sand contained in the combustion chamber.

The waste is then fed to the reactor via a pump, a star feeder or a screw-tube conveyor. Drying, volatilization, ignition and combustion take place in the fluidized bed. The temperature in the free space above the bed (the freeboard) is generally between 850 °C and 950 °C. Above the fluidized bed material, the freeboard is designed to allow retention of the gases in a combustion zone. In the bed itself the temperature is lower, and may be around 650 °C.

Because of the well-mixed nature of the reactor, fluidized bed incineration systems generally have a uniform distribution of temperatures and oxygen, which results in stable operation. For heterogeneous wastes, fluidized bed combustion requires a preparatory process step for the waste so that it conforms to size specifications. For some waste this may be achieved by a combination of selective collection of wastes or pretreatment, such as shredding. Some types of fluidized beds (for example, the rotating fluidized bed) can receive larger particle size wastes than others. Where this is the case the waste may only require a rough size reduction or none at all.

* + - 1. **Modular systems**

Modular systems are a general type of municipal solid waste incinerator used widely in the United States of America, Europe and Asia. Modular incinerators consist of two vertically mounted combustion chambers (a primary and secondary chamber). In modular configurations combustion, capacity typically ranges from 1 to 270 tons per day. There are two major types of modular systems, excess air and starved air.

The modular excess air system consists of a primary and a secondary combustion chamber, both of which operate with air levels in excess of stoichiometric requirements (i.e., 100–250 per cent excess air). In the starved (or controlled) air type of modular system, air is supplied to the primary chamber at sub-stoichiometric levels. The products of incomplete combustion entrain in the combustion gases that are formed in the primary combustion chamber and then pass into a secondary combustion chamber. Excess air is added to the secondary chamber, and combustion is completed by elevated temperatures sustained with auxiliary fuel (usually natural gas). The high, uniform temperature of the secondary chamber, combined with the turbulent mixing of the combustion gases, favours low levels of particulate matter and organic contaminants being formed and emitted.

* + 1. **Incineration of specific waste streams**
			1. **Municipal waste incineration**

Although in many areas landfilling of non-recycled waste remains the principal means for the disposal of municipal solid waste incineration and the subsequent landfilling of residues has become a common practice in many developed and industrializing countries.

Municipal solid waste incineration is commonly accompanied by the recovery of some calorific energy (“waste to energy”) in the form of steam and/or the generation of electricity. Incinerators can also be designed to accommodate processed forms of municipal solid waste-derived fuels, as well as co-firing with fossil fuels. Municipal waste incinerators can range in size from small package units processing single batches of only a few tons per day to very large units with continuous daily feed capacities in excess of a thousand tons.

The primary benefits of municipal solid waste incineration are the destruction of organic (including toxic) materials, the reduction in the volume of the waste and the concentration of pollutants (e.g., heavy metals) into comparatively small quantities of ashes, thus generating safe sinks if properly disposed of. The recovered energy can be an important additional benefit.

* + - * 1. **Operational considerations for municipal solid waste incinerators**

In many municipal solid waste incinerators, other waste fractions such as bulky waste, (e.g., from sorting plants), sewage sludge, medical waste or the high calorific fraction from waste pretreatment (e.g., from shredder plants) are also incinerated. These wastes have to be carefully evaluated prior to incineration to ascertain whether the waste incineration plant (including flue gas treatment, wastewater and residue treatment) is designed to handle these types of waste and whether it can do so without risk of harm to human health or the environment. Some important parameters are chlorine, bromine and sulfur content, heavy metals content, calorific content (lower heat value) and burnout behaviour.

High concentration of bromine may lead to the formation of brominated compounds such as polybrominated
Dibenzo-p-Dioxins (PBDD) and polybrominated di-benzo furans (PBDF) (CSTEE, 2002).

Mercury is volatized in the incineration process and therefore particular actions should be taken both before and after incineration to reduce these emissions. Neglecting the limits of the incineration plant will result in operational problems (e.g., the necessity of repeated shutdowns due to cleaning of the grate or heat exchangers) or in a bad environmental performance (e.g., high emissions into water, high leachability of fly ash). Figure 7 shows the typical layout of a large municipal solid waste incinerator.

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**Figure 4 Typical municipal solid waste incinerator (Source: European Commission 2006)**

* + - * 1. **Municipal solid waste incinerator designs**

Municipal solid waste can be incinerated in several combustion systems, including travelling grate, rotary kilns, and fluidized beds. Fluidized bed (see subsection 2.2.3.4) technology requires municipal solid waste to be of a certain particle size range – this usually requires some degree of pretreatment and the selective collection of the waste. Combustion capacities of municipal solid waste incinerators typically range from 90 to 2,700 tons of municipal solid waste per day (modular configurations: 4 to 270 tons per day).

Other processes have been developed that are based on the decoupling of the phases that also take place in an incinerator: drying, volatilization, pyrolysis, carbonization and oxidation of the waste. Gasification using gasifying agents such as steam, air, oxides of carbon or oxygen is also applied. These processes aim to reduce flue gas volumes and associated flue gas treatment costs. Many of these developments have come up against technical and economic problems when scaled up to commercial and industrial dimensions, and are therefore no longer pursued. Some are used on a commercial basis (e.g., in Japan) and others are being tested in demonstration plants throughout Europe, but still have only a small share of the overall treatment capacity when compared to incineration.

* + - 1. **Hazardous waste incineration**

Hazardous waste is commonly burned in rotary kilns or in grate incinerators. Other types of incinerators used for hazardous waste include fluidized beds, liquid injection units, and fixed hearth units. Before accepting a hazardous waste for treatment, merchant incinerators must assess and characterize the material. Documentation by the producer is routinely required, including the origin of the waste, its code or other designation, the identification of responsible persons and the presence of particular hazardous materials. The waste must also be properly packaged to avoid the possibility of reaction and emissions during transport.

Storage at the incinerator site will depend on the nature and physical properties of the waste. Solid hazardous waste is typically stored in bunkers constructed to prevent leakage into any environmental media and enclosed to allow the removal of bunker air to the combustion process. Liquid wastes are stored in tank farms, often under inert gas atmosphere (for example N2), and transported to the incinerator by pipeline. Some wastes may be fed directly to the incinerator in their transport containers. Pumps, pipelines and other equipment that may come into contact with the wastes must be corrosion-proof and accessible for cleaning and sampling. Pretreatment operations may include neutralization, drainage or solidification of the waste. Shredders and mechanical mixers may also be used to process containers or to blend wastes for more efficient combustion.

Hazardous waste is also incinerated in cement kilns. This application is addressed in the cement chapter of the guidance document.

* + - 1. **Sewage sludge incineration**

Domestic sewage sludge is disposed of in a number of ways, including application on agricultural land after pretreatment, surface disposal (e.g., landscaping, landfilling), incineration, co-disposal with municipal solid waste and co-incineration. The incineration of sewage sludge is practiced in several countries, either alone or through
co-incineration in municipal solid waste incinerators or in other combustion plants (e.g., coal-fired power plants, cement kilns). The effective disposal of sewage sludge by this process depends on a number of factors. These include whether the sewage is mixed with industrial waste streams (which can increase heavy metal loadings), location (coastal locations can result in salt water intrusion), pretreatment (or the lack thereof), and weather (rainfall dilution) (EU IED, 2010).

The incineration of sewage sludge presents some differences from the incineration of municipal solid waste and hazardous waste. The variability of moisture content, energy value, and possible mixture with other wastes (e.g., industrial waste if sewage systems are interconnected) require special considerations in handling and pretreatment.

Solid residues from sewage sludge incineration mainly consist of fly ash and bed ash (from fluidized bed incineration) and residues from flue gas treatment (see the description of municipal solid waste incineration in 2.2.4.1 above). Appropriate flue gas cleaning measures have to be combined in a suitable manner to ensure the application of best available techniques (see section 5.5 below).

* + - 1. **Design and operation of sewage sludge incinerators**

A typical sewage sludge incinerator may process as much as 80,000 tons of sewage sludge (35 per cent dry solids) per year. The incineration technologies of choice for sewage sludge are the multiple hearth (figure 5) and fluidized bed furnace systems, although rotary kilns are also used in smaller applications.



**Figure 5 Example of a multiple hearth sewage sludge incinerator (European Commission, 2006)**

Depending on the percentage of dry solids (dryness), an auxiliary fuel, usually heating oil or natural gas, is provided. The preferred operating temperatures are in the range of 850 °C–950 °C with a two-second residence time, although some fluidized bed facilities are able to operate at a temperature as low as 820 °C without deterioration in performance. Operation at or above 980 °C can cause ash to fuse (European Commission 2006).

Sewage sludge is co-incinerated with municipal solid waste in both fluidized bed and mass burn (grated) incinerators. In the latter case, a ratio of 1:3 (sludge to waste) is typical, with dried sludge introduced into the incineration chamber as a dust or drained sludge applied to the grate through sprinklers. In some cases, drained or dried sludge may be mixed with municipal solid waste in the bunker or hopper before being charged to the incinerator. The feeding methods represent a significant proportion of the additional capital investment required for co-incineration.

* + - * 1. **Pretreatment of sewage sludge**

Pretreatment, especially dewatering and drying, is of particular importance in preparing sludge for incineration. Drying reduces the volume of the sludge and increases the heat energy of the product. Moisture removal to at least 35 per cent dry solids is normally required to provide the necessary heat energy for autothermal incineration. Further drying may be necessary if co-incineration with municipal solid waste is envisaged.

Some pretreatment of sludge may occur before delivery to an incineration facility. This may include screening, anaerobic and aerobic digestion, and the addition of treatment chemicals.

Physical dewatering reduces sludge volume and increases heating value. Mechanical dewatering processes include decanters, centrifuges, belt filter and chamber filter presses. Conditioners (for example, flocking agents) are often added before dewatering to facilitate drainage. Mechanical dewatering can routinely achieve 20–35 per cent dry solids (European Commission, 2006).

Drying introduces heat to further dewater and condition the sludge. Heat for drying at the incineration facility is often provided by the incineration process itself. Drying processes can be direct (sludge contacts thermal carrier) or indirect (for example, heat supplied by steam plant). In direct drying, the vapour and gas mixture must be subsequently cleaned.

Autothermal (self-sustaining) incineration of sludge requires 35 per cent dry solids. Although mechanical dewatering can reach this threshold, additional drying of sludge to as much as 80–95 per cent dry solids may be employed to increase the heat value. Co-incineration with municipal solid waste generally requires additional sludge drying.

* + - 1. **Waste wood incineration**

Wood waste containing or contaminated with mercury can be burned in grate incinerators or in fluidized bed incinerators at the same temperatures as that applied to municipal waste incineration.

Another technique used is pyrolysis. Three products are usually produced: gas, pyrolysis oil and charcoal, the relative proportions of which depend very much on the pyrolysis method, the characteristics of the biomass and the reaction parameters. Fast or flash pyrolysis is used to maximize either gas or liquid products according to the temperature employed.

* + - 1. **Behaviour of mercury during the incineration process**

This section discusses the behaviour of mercury during the incineration process. As described in section 3, the ability of various controls to capture emissions is related to the speciation of mercury in the flue gas.

Owing to the thermo-chemical instability of mercury compounds, at temperatures above 700 °C–800 °C only elemental mercury exists. This means that inside the combustion chamber of a waste incinerator, mercury is present only in its elemental form. Mercury is highly volatile and, therefore, almost exclusively present in the vapour phase in the flue gas. On its way through the heat recovery section the flue gas cools down and the elemental mercury reacts depending on the presence of other flue gas components, temperature, and ash composition to oxidized mercury. The oxidized mercury compounds are generally unstable in the flue gas and under atmospheric conditions (Galbareth, Zygarlicke 1996).

Under certain conditions, elemental mercury can be oxidized. The extent of the conversion depends on the temperature, residence time, ash, unburnt carbon and the presence of gas-phase species including chlorine or SO2. The distribution of elemental mercury and oxidized mercury in the form of mercury (II) chloride depends strongly on the amount of HCl in the flue gas. The proportion of oxidized mercury and total mercury tend to increase with increasing hydrogen chloride concentration (Nishitani et al., 1999). Owing to the lower content of HCl in sewage sludge incineration plants, the share of elemental mercury is significantly higher.

1. **Emission control techniques**

The type and order of treatment processes applied to the flue gases once they leave the incineration chamber is important, both for optimal operation of the devices and for the overall cost-effectiveness of the installation. Waste incineration parameters that affect the selection of techniques include: waste type, composition, and variability; type of combustion process; flue gas flow and temperature; and the need for, and availability of, wastewater treatment. The following treatment techniques have direct or indirect impacts on preventing or reducing the emissions of mercury. BAT involves applying the most suitable combination of flue gas cleaning systems. General descriptions of a number of the techniques are provided in the introduction to this guidance (section 1). Information considered specific to waste incineration is presented in the following sections.

* 1. **Dust (particulate matter) removal techniques**

Dust removal from the flue gases is essential for all incinerator operations. Electrostatic precipitators (ESPs) and fabric filters (FFs) have demonstrated effectiveness as capture techniques for particulate matter in incinerator flue gases. For a description of the general principles of these techniques, see the introductory , of this document.

To more efficiently remove mercury from flue gas, both FFs and ESPs are used in combination with other techniques (see sections 3.4–3.5 below).

Pressure drop across fabric filters and flue gas temperature (if a scrubbing system is used upstream) should be monitored to ensure that the filter cake is in place and that bags are not leaking or getting wet.

Fabric filters are subject to water damage and corrosion and gas streams must be maintained above the dew point (130 °C–140 °C) to prevent these effects. Some filter materials are more resistant to damage.

*Cross-media effects on the leaching of mercury from fly ash* (EC, 2006, Waste Incineration)

The fly ash generated from flue gas cleaning systems should be handled with care since it has the potential to leach mercury into land and ground water.

*Cross-media effects (non-mercury-related)*

ESPs and FFs used in dust removal have high energy consumption due to electrostatic loading, high pressure drop and pulsing high pressure air cleaning. The residue amount is 12–20 kg/t waste input.

*Costs of installation and operation* (EC, 2006, Waste Incineration)

Investment costs for a two-line municipal solid waste incinerator of total capacity 200 000 t/yr are estimated as:

ESP (three field): €2.2 million
ESP (two field): €1.6 million
FF: €2.2 million (not clear if this includes an upstream flue gas cooler)

*Co-benefits on the use of FFs coupled with spray drying or semi-dry sorbent injection*

For separation of other pollutants such as dust, other heavy metals and dust-bonded organic compounds, fabric filters have the added advantage when coupled with dry or semi-dry sorbent injection (spray drying) of providing additional filtration and reactive surface on the filter cake.

* 1. **Wet scrubbing techniques**

Gaseous mercury can be captured by adsorption in a wet scrubber. In the first stage the removal efficiency of oxidized mercury as HgCl2 (which is generally the main compound of mercury after waste combustion) is over 95 per cent. (EC, 2006, Waste Incineration). The removal rates of elemental mercury, however, are only in the order of 0–10 per cent, mainly as a result of condensation at the scrubber operational temperature of around 60 °C–70 °C.

Precipitation is another measure often used to minimize the concentration of oxidized mercury in the scrubbing water. A flocculation agent (often a sulfur compound) is added to the scrubbing water and converts the soluble mercury into an insoluble compound with reasonable efficiency, particularly in the second stage. To bind the mercury directly after the conversion into the liquid phase, another possibility is to add activated carbon to the scrubbing water (Bittig 2014). Re-emission of dissolved mercury to the flue gas can be avoided by complexing the dissolved mercury with sequestering agents e.g., organic sulfides (Keiser et al., 2014).

With the measures mentioned above, elemental mercury adsorption can be improved from 20 per cent up to a maximum of 30 per cent. The overall mercury removal (both metallic and oxidized) efficiency is around 85 per cent (EC, 2006, Waste Incineration).

*Cross media effects*

Non mercury-related cross media effects are shown in table 1

**Table 1**

Cross-media effects – non-mercury-related

|  |  |
| --- | --- |
| Reagent consumption | 2–3 kg (NaOH) or 10 kg CaO or 5–10 kg lime stone per ton waste input |
| Residue amount: | 10–15 l/t waste input |
| Water consumption:  | 100–500 l/t waste input |
| Emissions to water:  | 250–500 l/t waste input |

*Source*: WT BREF 2005

Process wastewater in incineration arises mainly from the use of wet scrubbing techniques. Releases of wastewater can be avoided by injecting them into the flue gas with a spray absorber or a comparable system. For example, in Germany, there are only very few incineration plants which have water releases from flue gas treatment.

If there is no injection of wastewater into the flue gas, the scrubber effluents should be treated in a physico-chemical treatment installation. For the removal of mercury, a two-stage precipitation should be applied. With a combination of a two-stage precipitation with ultra filtration or a mercury specific ion exchanger, concentrations below 1 µg/l can be achieved (Marson et al, 2013, Riethman, 2013, Owens et al, 2013, Scheidereit 2014).

*Costs*

Costs of installation and operation are shown in table 2.

**Table 2**

Costs of installation and operation

|  |  |  |
| --- | --- | --- |
| FGT component | Estimated investment costs | Comments |
| Two-stage wet scrubber | €5 million | Including waste water treatment |
| Three-stage wet scrubber | €7 million | Including waste water treatment |
| External scrubber effluent evaporation plant | €1.5 million–€2 million |  |
| Spray absorber for internal effluent evaporation | € 1.5 million | Cost estimate believed to be on the low side |

*Source*: EC, 2006, Waste Incineration

*Information from a plant manufacturer from 2014*

For a 200,000 ton plant with two incineration and flue gas treatment lines: FF + 2 stage scrubber: €16 million–€18 million.

*Co-benefits of the use of carbon-impregnated materials*

For the separation of acid gases, dust and dust-bonded ingredients, the use of carbon-impregnated materials, activated carbon, or coke in scrubber packing materials can achieve 70 per cent reduction in polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) across the scrubber but this may not be reflected in overall releases (European Commission, 2006).

* 1. **Activated carbon injection**

The use of activated carbon to enhance the removal of mercury is described in a general way in the introductory chapter of this document. The activated carbon technique involves the injection of activated carbon or hearth furnace coke (HOK) upstream of a bag filter (see section 3.1 above) or other dedusting device. As a result, most of the mercury is then adsorbed at the filter layer. Accordingly, FFs are usually pre-coated with reagents before start-ups to ensure that a good abatement performance is already achieved when waste feeding starts.

A good mixture of the adsorbent materials with the flue gas and a sufficient contact time are important for a successful precipitation. Dosing of carbon-based adsorbents in the flue gas before a downstream fabric filter, e.g., after a scrubber is a well established last step of the gas cleaning.

Consideration of the speciation mix of the flue gas is key to estimating the mercury emission control efficiency of the activated carbon. In general, the oxidized species of mercury are considered more easily controlled than the elemental form. The halogen content of the waste is important in determining the amount of oxidation taking place. High halogen content in the flue gases, and thus high percentages of oxidized mercury, may often exist in municipal waste incinerators. The removal efficiency of the injection of activated carbon in combination with a FF can be as high as 95 per cent.

The separate injection of activated carbon, controlled by continuous mercury monitoring in the raw gas, has proved to be very effective in waste incineration. In this way the added amount of activated carbon can be adapted to the raw gas concentrations of mercury. In addition, in the event of mercury peaks in the raw gas, highly effective activated carbon impregnated with about 25 per cent sulfur can be injected. This approach combines an effective mercury abatement with the decreased operation costs resulting from a reduced use of sorbents. It should be noted that the investment costs of a mercury gas measuring device could be significantly lower than those for a clean gas device because measurement devices tested for suitability are not necessary (Esser-Schmittmann 2012).

In particular, in cases where there are relatively high concentrations of elemental mercury in the flue gas, e.g., at sewage sludge incineration plants, satisfactory reduction efficiencies can only be achieved when activated carbon impregnated with sulfuric acid or halogen (e.g., bromine) is used.

Tests have shown that the Hg reduction ratio increases as the flue gas temperature decreases and that the reduction efficiency is significantly higher when there are high concentrations of mercury in the raw gas (Takaoka et al. 2002).

The removal efficiency of the carbon sorbents increases if a fabric filter is used instead of an ESP, owing to the longer residence timen allowing more contact between the sorbent and the mercury-laden flue gas. As a result, only a third of the sorbent is needed to capture the same amount of mercury compared to an ESP (LCP BREF Draft 2013).

For a more effective removal of mercury from flue gases, use is made of specially developed activated carbon impregnated with sulfuric acid, elemental sulfur or bromine. In this case, the removal of mercury is driven by chemisorption, and also by physisorption. Tests have shown that the mercury reduction efficiency can be increased to 99 per cent.

*Cross-media effects (non-mercury-related)*

Carbon consumption rates of 3 kg/ton of waste are typical for municipal solid waste incineration. Levels ranging from 0.3 to 20 kg/ton of hazardous waste have been reported (EC, 2006, Waste Incineration).

*Costs of installation and operation*

For a 200,000 ton plant with two incineration and flue gas treatment lines: the costs of dry flue gas treatment, including storage of sorbents, dosing systems, control of sorbent injection, FF and ash discharge, range between €5.5 million and €6 million installation cost.

The installation costs for storage of the activated carbon are approximately €50,000 for smaller plants (container storage) and approximately €100,000 for bigger plants (silo storage) (data from Germany, 2014).

The operation costs depend on the kind of carbon which is used. For HOK the cost is approximately €300 per ton; for weak sulfuric acid-impregnated carbon (5 per cent) approximately €400 per ton; for high sulfur-impregnated carbon approximately €2,000 per ton; and for bromated activated carbon approximately €1,500 per ton.

The usage of low sulfuric acid-impregnated carbon for a 300,000 ton municipal waste incineration plant is estimated at 30 t/y for a plant using a police filter and 200 t/y for a plant equipped with a dry flue gas treatment system (data from Germany, 2014).

*Co-benefits*

Separation of volatile organic compounds such as dioxins can also be achieved in the flue gas. It is normal for alkaline reagents to be added together with the carbon; this then also allows the reduction of acid gases in the same process step as a multifunctional device.

* 1. **Boiler bromide addition**

Addition of bromide into the furnace can enhance the oxidation of mercury during the passage through the boiler of the flue-gas, thereby promoting the transformation of insoluble elemental gaseous mercury into its water-soluble mercury (II) bromide (HgBr2), and also into adsorbable mercury species. Mercury removal can thereby be enhanced in existing downstream control devices, such as wet scrubbers. Another option for the addition of halogens is to add bromide or other halogen compounds to the waste (Vosteen 2006).

It should be noted that boiler bromide addition (BBA) alone does not reduce mercury emissions as such, in the sense of capturing elemental mercury as HgBr2. BBA promotes mercury oxidation and thereby indirectly reduces mercury emissions at existing wet air pollution control (APC) systems as wet desulfurization scrubbers or dry desulfurization scrubbers; thus, BBA improves the efficiency of activated carbon injected at units with particulate scrubbers (ESP, FF) (LCP BREF Draft Version 2013).

In waste incineration plants, this technique is beneficial in cases where the waste contains low levels of halogens. It is therefore applied mainly in sewage sludge incineration plants and hazardous waste incineration plants burning waste with low halogen levels. For example, in a German waste incineration plant for hazardous waste, flue gas is monitored continuously. The monitoring takes place after the wet scrubber, but before the tail-end selective catalytic reduction (SCR), because SCR devices retain mercury and this is then slowly released again. If a significant increase of mercury is detected after the wet scrubber, bromine compounds are injected into the boiler. This results in considerably lower mercury emissions in the clean flue gas (Vosteen, 2006). This technique is not effective in the case of very short mercury peaks in the flue gas, because the peak has passed the flue gas treatment system before there is a possibility to react.

In general, it was reported that, by applying Br/Hg mass ratios of more than 300, complete mercury oxidation can be achieved. It has recently been demonstrated at two French hazardous waste incineration plants using mainly dry flue gas cleaning that the mercury removal efficiency associated with the use of activated carbon was almost 100 per cent. This efficiency was seen in the present of almost only oxidized mercury (Chaucherie et al., 2015). A similar removal efficiency of 99.8 per cent was achieved with a multistage scrubbing system.

The use of bromine in the process may lead to the formation of polybrominated dioxins and polyhalogenated dioxins and furans which are undesirable. It should be noted that emissions of these substances, if occurring, need to be controlled.

*Cross-media effects*

Mercury measurements can be very difficult if bromine is present in the flue gas. There is a potential for
bromine-induced corrosion in the ductwork, air heater and in flue gas desulfurization (FGD) systems. Bromine-induced corrosion commonly goes together with an increased bromine and mercury content in the fly ash (LCP BREF Draft Version, 2013).

*Costs of installation and operation*

The use of activated carbon injection in conjunction with BBA may be more cost-effective than the use of either method alone in order to achieve the same level of performance.

* 1. **Static bed filters**

Activated coke moving bed filters are used as a secondary cleaning process in the flue gas of municipal and hazardous waste incineration plants. Using this adsorption system, it is possible to deposit substances contained in the flue gas at low concentrations with efficiencies as high as 99 per cent. Lignite coke produced in hearth furnace coke process is used in moving bed absorbers.

The flue gases pass through a filling of grained hearth furnace coke (HFC) – a fine coke of 1.25 mm–5 mm). The depositing effect of HFC is essentially based on adsorption and filtration mechanisms. It is thus possible to deposit almost all emission-relevant flue-gas components, in particular, residual contents of hydrochloric acid, hydrofluoric acid, sulfur oxides, and heavy metals (including mercury), to levels sometimes below the detection limit.

The flue gas is guided to the activated coke filling over a distributor bed equipped with a multitude of double funnels. The gas flows through them from the bottom to the top, while the HFC passes through the absorber from the top to the bottom. This makes possible an ideal distribution of the flue gas over the entire cross-section of the absorber, with optimal use of the capacity of the absorber and minimum consumption of the activated coke.

An essential feature of the moving bed system is its high efficiency with all emissions, due to the large bulk of activated coke, so that variations from incineration and upstream flue-gas cleaning caused by operation will not have disadvantageous effects.

Because of the carbon contained in the static bed filters, there is a possibility of fire outbreak. As a result of fire risk and high costs, the systems are installed only in few plants. Care should be taken to avoid any fire outbreak, including through the installation of a dampening system.

*Cross-media effects that are non-mercury-related* (WT BREF 2005)

The non-mercury-related cross-media effects include the following:

* Energy consumption: 30–35 kWh/ton waste input
* Reagent consumption: 1 kg/ton waste input
* Residue amount: 0–1 kg/ton waste input

*Costs of installation and operation of coke filter*

The investment cost of a coke filter for a 100,000 ton/y municipal solid waste incinerator was estimated at €1.2 million. The investment costs for one static bed wet filter (empty) (incineration line of 50,000 t/y) is approximately €1 million (EC, 2006, Waste Incineration)

*Co-benefits*

The co-benefits of using activated coke bed-moving filter include the separation of volatile organic compounds, such as dioxins, in the flue gas.

* 1. **Illustrative examples for emission values achieved with the techniques described above.**

The following tables and figures illustrate performance achieved with the application of the above techniques. Figure 6 shows annual mean values of mercury emissions for different combined or one-step waste gas control techniques of 51 plants used for incineration of municipal, medical and hazardous waste from plants in Germany. All plants are equipped with continuous mercury measurement. For each technique combination, the mean of all reported values is indicated (centre line) together with the standard variation (orange) and the minimum and maximum values (grey).

The mean annual emission value is about 2.5 µg/Nm3 (yearly average based on daily averages), similar for all combinations of control techniques installed. More than 90 per cent of the installations emit less than 10 µg/m3. All applied combinations of techniques are appropriate for mercury reduction, as demonstrated by the small ranges of the annual emission values reported for each combination.

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**Figure 6 Comparison of waste gas control techniques for mercury reduction (number of plants in brackets) (Daschner et al., 2011)**

Actual measurement data from industrial waste and municipal waste incinerators in Japan is shown in Table 3 and 4. In the case of industrial waste incinerators, however, there is a large deviation in mercury concentrations of flue gas. It should be noted that not all of these plants, municipal waste incineration as well as hazardous waste incineration, use activated carbon. Better performance is generally achieved at installations with injection of activated carbon.

**Table 3**

Distribution of mercury concentration (mg/Nm3) of flue gas by flue gas treatment technology (municipal waste incinerator)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Flue gas treatment type | Min. | Arithmetic mean | Max. | Standard deviation σ |
| FF + Slaked lime injection (dry) (86 incinerators) | 0.0005 | 0.0176 | 0.165 | 0.022 |
| FF + Scrubber (32 incinerators) | 0.0002 | 0.0114 | 0.074 | 0.015 |
| FF + (Slaked lime or scrubber) + Activated carbon treatment (229 incinerators) | 0.0002 | 0.0081 | 0.249 | 0.020 |
| ESP + Scrubber (9 incinerators) | 0.004 | 0.0154 | 0.047 | 0.014 |
| ESP + Scrubber + Activated carbon treatment (11 incinerators) | 0.0005 | 0.0043 | 0.014 | 0.004 |

Activated carbon treatment: Activated carbon injection, activated carbon adsorption tower or activated coke adsorption

**Table 4**

Distribution of mercury concentration (mg/Nm3) of flue gas by flue gas treatment technology (industrial waste incinerator)

| **Type of flue gas treatment, business permit**  |  | **Min.** | **Arithmetic mean** | **Max.** | **Standard deviation σ** |
| --- | --- | --- | --- | --- | --- |
| **FF (with dry or wet system)**Industrial wastea (18 incinerators) | \*1 | 0.0001 | 0.0057 | 0.046 | 0.010 |
| **FF (with dry or wet system)**Infectious waste or industrial hazardous waste (15 incinerators) | \*1 | 0.0002 | 0.0062 | 0.039 | 0.0084 |
| **FF + Scrubber (liquid chelating agent added)**Industrial waste, infectious waste or industrial hazardous waste (5 incinerators) | \*2 | 0.0004 | 0.0064 | 0.035 | 0.0077 |
| **ESP + Scrubber**Industrial waste, infectious waste or industrial hazardous waste (7 incinerators) | \*3 | 0.0001 | 0.035 | 0.210 | 0.051 |

a The term “industrial waste” here does not include industrial hazardous waste.

\*1 : Incinerators with flue gas treatment by fabric filters (FF) and one or more of the following: scrubbers (water or alkali washing), activated carbon injection, activated carbon adsorption tower or catalytic reactor

\*2：Incinerators with flue gas treatment by a combination of FF and scrubbing solution added with liquid chelating agent for mercury removal.

\*3：Incinerators with flue gas treatment by a combination of electrostatic precipitator (dry or wet) and scrubbers. Some of the incinerators also have activated carbon injection (continuous) or activated carbon adsorption towers.

Trials at a Japanese stoker-fired waste incineration plant for municipal waste equipped with a spray tower and following Ca(OH)2 and ACI injection before a FF showed emission levels in a range between 0.4 and 11.3 µg/m3 (Takaoka 2002).

The figure and the tables in section 3.6 show that at almost all installations concentrations below 10 µg/m3 can be achieved, especially when activated carbon is used in combination with other techniques. Some plants in Europe and Japan show mercury emission concentrations below 1 µg/m3.

* 1. **Use and disposal of solid residues from incineration**

Although this guidance is primarily concerned with air emissions, account should also be taken of cross-media effects. Accordingly, the following section provides information on managing residual waste from the incineration process, including preventing or minimizing risks of leaching or distribution through the environment through a number of pathways.

Wastes and residues from incineration include various types of ash (e.g., bottom ash, boiler ash, fly ash) and residues from other flue gas treatment processes (such as gypsum from wet scrubbers), including liquid effluents in the case of wet scrubbing systems.

Because constituents of concern may vary considerably, maintaining the separation of residues for treatment, management and disposal is generally advisable. The presence and concentration of mercury and its compounds in these residues (if separately treated) is a function of their presence in the incoming waste and capture during flue gas treatment. Air pollution control residues in particular should be treated in such a manner as to avoid additional evaporation or the leaking of mercury and its compounds.

The release of contaminants from these dry materials into the environment may occur via a number of routes, including: wind-blown dust, leaching to groundwater, plant uptake or direct ingestion by humans, domesticated animals and wildlife. Management of these materials must be carried out with due consideration of these potential releases.

* + 1. **Treatment of solid flue gas residues**

One major flue gas treatment residue (or air pollution control residue) is fly ash. Fly ash removal from flue gas by use of dry scrubbers, cyclones or fabric filters in waste incinerators will result in dry and fine solid particulate material acquiring a range of properties and contaminants depending on the combustion source that produced it. Unlike bottom ash, air pollution control device residuals, including fly ash and scrubber sludges, contain relatively high concentrations of heavy metals, persistent organic pollutants, chlorides and sulfides. The separate removal of fly ash and residues from flue gas cleaning stages (e.g., those for acid gas and dioxin removal) prevents the mixing of low contaminated waste fractions with those that are highly contaminated. Most mercury in waste streams ends up in the residues when pollution abatement measures are installed ([European Commission 200](#_ENREF_2)6, [Song, Kim et al. 2004](#_ENREF_6)).

In Switzerland the treatment of fly ash with acid wastewater from the scrubber is widespread. To avoid mercury contamination of the treated ash, the acid wastewater is first cleaned with a candle filter, followed by a mercury-specific ion-exchange unit. This waster, from which mercury has been removed, can be used to wash heavy metals from the fly ashes. The wash water is subsequently treated in a classic flocculation and precipitation unit. For the final cleaning of the wastewater a second ion exchanger is used.

The cleaned fly ash can be added to waste in the waste incineration plant to destroy the organic components in the fly ash (Bühler et al. 2015, Adam et al. 2010, BSH 2015).

Fly ash is disposed of in dedicated landfills in many countries. To meet BAT standards, however, pretreatment is likely to be required for this (see, for example, [Song, Kim et al. 2004](#_ENREF_6)), depending on national landfill acceptance criteria. More detailed information on waste incinerator residues containing mercury management can be found in the Basel Convention ESM technical guidance for mercury wastes ([Basel Convention Secretariat 201](#_ENREF_1)5).

* + 1. **Stabilization and solidification**

Treatment and disposal options for solid residues from flue gas control systems include solidification or stabilization with Portland cement (or other pozzolanic materials), alone or with additives or a number of thermally based treatments, followed by appropriate disposal in conformity with national landfill acceptance criteria (based on anticipated releases from the treated residuals). The need for such treatment can be determined based on an evaluation of the release potential of these residues. More detailed information on treatment methods can be found in the Basel Convention ESM technical guidance for mercury wastes ([Basel Convention Secretariat 201](#_ENREF_1)5)

* + 1. **Bottom and fly ash use**

Because of the differences in pollutant concentration, the mixing of bottom ash with fly ash will contaminate the former and is forbidden in many countries. The separate collection and storage of these residues may provide operators with more options for disposal. Whenever bottom ash is to be further used (e.g., as construction material), mixing with other flue gas treatment residues is generally not a BAT. Bottom ash (or slag from fluidized bed incinerators) is disposed of in landfills in many countries but may be reused in construction and road-building material following pretreatment. Prior to such use, however, an assessment of content and leachability should be conducted and upper levels of heavy metals and persistent organic pollutants should be determined. Pretreatment techniques include dry, wet and thermal treatment, and also the screening, crushing and separation of metals.

The use of fly ash and mixed waste incineration residues for construction purposes has potential environmental risks due to contamination by heavy metals There are examples which demonstrate that such practice can lead to serious environmental contamination ([Pless-Mulloli, Edwards et al. 2001](#_ENREF_4); Watson 2001; Petrlik and Ryder 2005; Shaheen et al. 2014).

Bottom and fly ashes from waste incinerators should never be used as soil amendment in agricultural or similar applications if their mercury concentration exceed levels of concern. Addition to soil may result in subsequent dispersion of the ash and any contaminants. In agricultural uses, plants may take up contaminants, resulting in exposure to human or animals that consume such plants (Skinner et al, 2007). Pecking or grazing animals may directly ingest contaminants with subsequent exposure to humans when they consume the animals or animal products (e.g., milk and eggs) (de Vries et al., 2007). .

* + 1. **Final disposal of residues**

If there is recycling of materials other than mercury in the waste, adequate precautions should be taken to prevent emissions of mercury from that process. When disposed of in a landfill, evaluation of the release potential and the appropriateness of the landfill for this type of material should be considered. More detailed information can be found in the technical guidelines for the environmentally sound management of wastes consisting of elemental mercury and waste containing or contaminated with mercury or mercury compounds ([Basel Convention, 201](#_ENREF_1)5).

* 1. **Alternative treatment techniques for waste streams that can generate emission of mercury and mercury compounds when incinerated**

This section describes some alternative treatment technologies that are currently commercially available. The goal of an alternative treatment technology would be to achieve the same degree of destruction of the organic compounds, while controlling potential releases of residual mercury.

For municipal waste, possible alternatives to incineration are:

* Zero waste management strategies which aim to eliminate the generation of waste through the application of a variety of measures, including legislative and economic instruments (circular economic policy and recycling insurance) ([Greyson, 2007](#_ENREF_6); [Matete and Trois, 2008](#_ENREF_9); [Allen, Gokaldas et al., 2012](#_ENREF_1));
* Waste minimization, source separation and recycling to reduce the waste volume requiring final disposal;
* Mechanical biological treatment, which reduces waste volume by mechanical and biological means and generates residues requiring further management ([Bilitewski, Oros et al. 2010](#_ENREF_4)); ([Velis, Longhurst et al. 2009](#_ENREF_10)).

For medical waste, possible alternatives to incineration use are:

* Exposure of waste to saturated steam under pressure in a pressure vessel or autoclave;
* Advanced steam sterilization systems. Advanced autoclaves or advanced steam sterilization systems combine steam treatment with pre-vacuuming and various kinds of mechanical processing before, during and after steam treatment;
* Microwave treatment;
* Dry heat sterilization.

These alternatives are well described in the Stockholm Convention BAT/BEP Guidelines (Stockholm Convention, 2008) and in the UNEP Compendium of Technologies for Treatment/Destruction of Healthcare Waste (Emmanuel, 2012). UNEP has also developed an interactive Excel-based software that facilitates use of the sustainable assessment of technologies methodology for selecting health-care waste treatment technologies (Emmanuel, 2012).

For hazardous wastes, some possible alternatives are listed in chapter III of the Basel Convention Technical Guidelines on Mercury Waste (Basel Convention, 2015) and, in particular for soil contaminated with mercury, also in Bell’s study of contaminated sites in Kazakhstan (Bell, 2015)

1. **BAT and BEP for waste incineration facilities**
	1. **Introduction to BAT for the incineration of waste**

The purpose of this section is to assist in the identification of the best techniques applicable to the process of waste incineration. BAT for waste incineration include the design, operation and maintenance of a waste incineration plant that effectively minimizes the emissions of mercury.

When considering the BAT for waste incineration, it is important to consider that the optimal solution for a particular type of incineration installation varies according to local conditions. The techniques provided here are not intended as a checklist indicating the best local solution, as this would require the consideration of local conditions to a degree that cannot be described in a document dealing with best available techniques in general. Hence, the simple combination of the individual elements described here as BAT, without consideration of local conditions, is not likely to give the optimized local solution in relation to the environment as a whole (European Commission 2006).

With a suitable combination of primary and secondary measures associated with BAT, mercury emission levels not higher than 10 µg/m3 (at 11 per cent O2) have been reported (Daschner et al., 2011). It is further noted that under normal operating conditions emissions lower than than 1 µg/m3 can be achieved with a well-designed waste incineration plant (see section 5.5.2 below). There are many waste incinerator plants worldwide that are designed and operated according to most of the parameters defining BAT and that meet the associated emission levels. New plants could be expected to achieve these levels.

Small incineration installations, including medical waste incinerators, can pose problems in applying BAT. Some
non-incineration techniques, as described in the Basel Convention ESM technical guidance for mercury waste (see section 3.7 of the present document) and section II of the Stockholm Convention guidelines on BAT and BEP may represent feasible and environmentally sound alternatives to incineration.

* 1. **Pretreatment of waste before incineration**

The mixing (e.g., using bunker crane mixing) or further pretreatment (e.g., the blending of some liquid and pasty wastes, or the shredding of some solid wastes) of heterogeneous wastes to the degree required to meet the design specifications of the receiving installation is important. Pretreatment is most likely to be a requirement where the installation has been designed for a narrow specification, homogeneous waste.

* 1. **BAT for waste input and control**

The following general practice for waste input and control should be considered when dealing with BAT for handling waste containing or contaminated with mercury:

* Maintain the site in a generally tidy and clean state;
* Establish and maintain quality controls over the waste input, according to the types of waste that may be received at the installation. This could include:
	+ Establishing process input limitations and identifying key risks;
	+ Communicating with waste suppliers to improve incoming waste quality control;
	+ Controlling waste feed quality on the incinerator site;
	+ Checking, sampling and testing incoming wastes.
	1. **BAT for waste incineration**

There is a potential trade-off to be made in operating waste incinerators. To achieve the highest-level destruction, the aim is complete combustion. The following section describes, first, the general considerations which are likely to lead to achieving maximum combustion. There then follows a description of particular considerations for individual waste streams. The selection of a combustion technique will depend on the type of waste to be incinerated.

* + 1. **General conditions for combustion techniques**

The following conditions are important for achieving optimal combustion:

* Ensure that the furnace design is appropriately matched to characteristics of the waste to be processed;
* Maintain temperatures in the gas phase combustion zones in the optimal range for completing oxidation of the waste (for example, 850 °C–950 °C in grated municipal solid waste incinerators, 1,100 °C–1,200 °C when chlorine content of waste is high);
* Provide for sufficient residence time (e.g., at least two seconds) and turbulent mixing in the combustion chambers to complete incineration;
* Preheat primary and secondary air to assist combustion if necessary;
* Use continuous rather than batch processing wherever possible to minimize start-up and shutdown releases;
* Establish systems to monitor critical combustion parameters such as temperature, pressure drop, levels of CO and O2 and, where applicable, grate speed;
* Provide for control interventions to adjust waste feed, grate speed, and temperature, volume and distribution of primary and secondary air;
* Install automatic auxiliary burners to maintain optimal temperatures in the combustion chambers;
* Use air from bunker and storage facilities as combustion air;
* Install system that automatically stops waste feeding when combustion parameters are not appropriate.
	+ 1. **Municipal solid waste incineration techniques**

The following are considerations that are specific for the incineration of municipal solid waste:

* Mass burn (moving grate) incinerators are well demonstrated in the combustion of heterogeneous municipal solid waste and have a long operational history;
* Water-cooled grated incinerators have the added advantages of better combustion control and the ability to process municipal solid waste with higher heat content;
* Rotary kilns with grates can accept heterogeneous municipal solid waste but a lower throughput than the mass burn or moving grate furnaces;
* Static grated furnaces with transport systems (for example, rams) have fewer moving parts but waste may require more pretreatment (i.e., shredding, separation);
* Modular designs with secondary combustion chambers are widely used for smaller applications. Depending on size, some of these units may require batch operation;
* Fluidized bed furnaces and spreader or stoker furnaces are widely used for finely divided, consistent wastes such as refuse-derived fuel.
	+ 1. **Hazardous waste incineration techniques**

The following are considerations that are specific for the incineration of hazardous waste:

* Rotary kilns are widely used for the incineration of hazardous waste and can accept liquids and pastes as well as solids (see subsections 2.2.3.13.1–2.2.3.5);
* Liquid injection incinerators are commonly used for hazardous waste incineration;
* Water-cooled kilns can be operated at higher temperatures and allow the acceptance of wastes with higher energy values;
* Waste consistency (and combustion) can be improved by shredding drums and other packaged hazardous wastes;
* A feed equalization system (for example, screw conveyors that can crush and provide a constant amount of solid hazardous waste to the furnace) will help ensure a continuous, controlled feed to the kiln and maintenance of uniform combustion conditions.
	+ 1. **Sewage sludge incineration techniques**

The following are considerations that are specific for the incineration of sewage sludge

* Fluidized bed incinerators and multiple hearth incinerators are widely used for the thermal treatment of sewage sludge;
* Circulating fluid bed furnaces allow greater fuel flexibility than bubbling beds, but require cyclones to conserve bed material;
* Care must be exercised with bubbling bed units to avoid clogging;
* The use of heat recovered from the process to aid sludge drying will reduce the need for auxiliary fuel;
* Supply technologies are important in the co-incineration of sewage sludge in municipal solid waste incinerators. Demonstrated techniques include: dried sludge blown in as dust; drained sludge supplied through sprinklers and distributed and mixed on the grate; and drained or dried sludge mixed with municipal solid waste and fed together (European Commission 2006).
	+ 1. **Medical waste incineration**

The following are considerations that are specific for the incineration of medical waste

* Where grates are used, the design of the grate should incorporate sufficient cooling that it permits the variation of the primary air supply for the main purpose of combustion control, rather than for the cooling of the grate itself. Air-cooled grates with well distributed air cooling flow are generally suitable for wastes of net calorific value (NCV) of up to approximately 18 MJ/kg. Higher NCV wastes (e.g., above approximately 18 MJ/kg) may require water (or other liquid) cooling in order to prevent the need for excessive primary air levels to control grate temperature – i.e., levels that result in a greater air supply than the optimum for combustion control;
* Use should be made of a combustion chamber design that provides for containment, agitation and transport of the waste, such as rotary kilns – either with or without water cooling. Water cooling for rotary kilns may be favourable in situations where:
	+ The NCV of the feed waste is higher (e.g., more than 15–17 GJ/tonne);
	+ Higher temperatures – above 1,100 °C – are used (e.g., for slagging or destruction of specific wastes);
* Medical waste can be incinerated in municipal waste incinerators using the grate type of incinerator, although some special adaptations have to be made. If infectious medical waste is to be burnt in a municipal waste incinerator, it must be disinfected and sterilized beforehand or fed into the incinerator in appropriate containers by automatic loading (Stockholm Convention, 2008). The previous mixing of medical waste containing or contaminated with mercury with other waste types and direct handling should be avoided.
	1. **BAT for flue-gas treatment**

In this subsection, techniques that could be considered in selecting BAT for the flue gas treatment of waste incineration plants are described. Unless otherwise stated, these are generally applicable for new and existing facilities. It also includes guidance on the upgrading of existing facilities.

FFs are commonly used, and have the advantage, when coupled with semi-dry or dry sorbent injection, they provide additional filtration and reactive surface on the filter cake. In combination with wet systems, ESPs can also be designed and operated to reach low mercury emissions. FFs have advantages in comparison with ESPs, especially when they are precoated with activated carbon for absorption of volatile pollutants; an additional advantage is good abatement directly after the start-up phase. Dry and semi-dry systems have the advantage of not requiring subsequent effluent treatment. The inlet temperature to the FF in such combinations is important. Temperatures above 130 °C–140 °C are normally required to prevent condensation and corrosion of the bags.

When using a dry system, the injection of activated carbon (which may also be impregnated with sorbents like sulfur, bromine or others), mixed with sodium hydrogen carbonate or calcium hydroxide upstream of a fabric filter can reduce the mercury emissions by more than 95 per cent. Effective and continuous maintenance of dust control systems is essential.

In the first stage of a high efficiency scrubber the removal efficiency of oxidized mercury as mercury (II) chloride – which is generally the main compound of mercury after waste combustion – is over 95 per cent. The overall mercury removal (both elemental and oxidized) efficiency is around 85 per cent.

As additional measure for minimizing mercury in the scrubbing water and avoiding re-emission of the soluble mercury, the precipitation of oxidized mercury with a suitable precipitating agent, e.g., sulfide, and the addition of activated carbon can be used.

Especially at low concentrations of halogens in the waste, bromine addition into the waste or boiler can lead to high oxidation rates of mercury, thereby improving the mercury removal in downstream control devices, e.g., scrubbers (see also section 3.4). The technique is mainly used in mono-combustion plants for sewage sludge and hazardous waste incineration plants.

With these applications, the concentration of mercury below 10 µg/m³ (yearly average) has been reported (UNECE, 2013). In general, the use of fabric filters can give low levels within this emission range. With many wastes, adsorption using carbon-based reagents is generally required to achieve these emission levels. Some waste streams have highly variable mercury concentrations and waste pretreatment may be required in such cases to prevent peak overloading of the flue gas treatment system capacity.

For wastes with high levels of mercury, such as hazardous or medical wastes, the combination of various flue gas treatment steps can be appropriate. For example, a scrubber with oxidation ingredients and activated carbon injection before a fabric filter can be used.

The most relevant secondary emission reduction measures are outlined in table 5. If the re-burn of flue gas treatment residues is applied, suitable measures should be taken to avoid the recirculation and accumulation of mercury in the installation.

SCR for the control of nitrogen oxides also reduces mercury emissions as a co-benefit by changing the mercury into a form that can be collected by FF or precipitated by wet scrubbers.

Pressure drop across fabric filters and flue gas temperature (if a scrubbing system is used upstream) should be monitored to ensure that filter cake is in place and bags are not leaking or being wetted.

Where temporary peak mercury concentrations are to be expected, the retention and injection of sulfur-impregnated activated carbon or coke should be considered as a safety precaution.

Reduction efficiencies depend on mercury input, concentrations in the raw gas and operating conditions.

**Table 5**

Control measures and reduction efficiencies for municipal, medical and hazardous waste incineration for stack gases

|  |  |
| --- | --- |
| **Control measure** | **Reduction efficiency** |
| High efficiency scrubbers with ingredients in the scrubber liquor | > 85% |
| Scrubber + injection of bromine-containing chemicals into the combustion chamber | > 90% |
| Activated carbon injection + FF | > 95% |

*Source*: European Commission 2006

* + 1. **Upgrading and improvement of existing treatment techniques**

There are various options for upgrading exhaust gas treatment of existing plants. In systems equipped with an ESP, the ESP may be replaced by a fabric filter. In the flue gas stream ahead of the fabric filter, coke-based adsorbents (or substances with equivalent effects) have to be added to reduce mercury emissions. To minimize potential fire hazards a mixture with limestone reagents may be used.

In case of high mercury emissions at facilities equipped only with a scrubber, a combination of additive injection, with fabric filters, can be installed downstream.

Both measures have the added benefit that acidic and organic pollutants can also be removed from the flue gas. Owing, however, to increased fire hazards, the addition of a static-bed filter with activated carbon or lignite coke requires additional security measures.

* + 1. **Performance levels associated with the use of BAT**

With the combination of techniques described in section 5.5, mercury concentrations in the clean gas no higher than 10 µg/m3 have been reported. The figure and the tables in section 3.6 show that at almost all installations concentrations below 10 µg/m3 can be achieved, in particular when activated carbon is used in combination with other techniques. Some plants in Europe and Japan show mercury concentrations below 1 µg/m3 when activated carbon is used.

* 1. **Introduction to BEP**

Best environmental practices (BEP), as defined in the Minamata Convention, means the application of the most appropriate combination of environmental control measures and strategies. The following graduated range of measures should be considered in applying BEP:

* Regulatory infrastructure with sufficient capacity to permit incinerators, control and monitor mercury emissions regularly;
* Provision of information and education to the public, users and decision makers about the environmental consequences of choice of particular activities and choice of products, and ultimate disposal;
* Development and application of codes of good environmental practice, which covers all aspects of the activity in the product’s life;
* Application of labels to guide those handling the waste stream to direct components to proper treatment;
* Application of labels informing consumers of environmental risks, enabling them to make informed decision about choice;
* Use of resources, including energy;
* Integrating waste collection and disposal systems into residential, commercial and industrial processes to ensure that all waste is managed in an environmentally sound manner;
* Avoiding the use of hazardous substances or products that contain hazardous substances and the generation of hazardous waste;
* Recycling, recovery and reuse;
* Application of economic instruments, systems of licencing, restrictions, bans, certifications, standards or other policy tools;
* Evaluation of the mercury life cycle as an important perspective for the ESM of mercury wastes, in the effort to reduce mercury input into the waste incineration process (see Basel Convention technical guidelines).
* Recognizing importance of public participation in permitting processes. Effective practices for improving public awareness and involvement include: placing advance notices in newspapers; distributing information to area households; soliciting comments on the design and operational options; providing information displays in public spaces; maintaining pollutant release and transfer registers; and holding frequent public meetings and discussion forums. Authorities and proposers of incineration projects should engage with all stakeholders, including the public interest groups. Consultations with the public must be transparent, meaningful and sincere if they are to be effective.
	+ 1. **Waste management practices**

The approaches outlined below, must be taken into account as part of overall waste prevention and control strategies for mercury containing or contaminated waste.

To be sustainable, waste management cannot be solved only with technical end-of-pipe solutions; instead an integrated approach is necessary. This may be described as a hierarchical approach, as set out in section 2.1.1. Waste contaminated with or containing mercury should be dealt with according to Article 11 of the Convention.

* + - 1. **Waste minimization**

Reducing the overall mass of wastes that have to be disposed of by any means serves to reduce both the releases and residues from incinerators.

* + - 1. **Source separation and recycling**

In many industrialized countries, health care institutions have begun to phase-out mercury uses and phase-in effective alternative products or devices that avoid the use of mercury. A co-benefit of mercury-free alternatives is a reduction of the generation of mercury-containing waste. Many health care institutions have also instituted housekeeping and management practices to improve the control of mercury releases from sources still present in their facilities. Such policies and practices substantially decrease emissions and releases of mercury to the environment. Source separation and recycling represent an important part of an integral approach to waste management in the health care sector that leads to minimization of hazardous waste requiring special treatment due to its infectious properties as demonstrated in table 6 (Emmanuel, 2012).

|  |  |  |
| --- | --- | --- |
| **Level of Segregation**  | **% Hazardous Healthcare Waste**  | **% General Non-Risk Waste**  |
| Poor  | 60  | 40  |
| Fair  | 25  | 75  |
| Rigorous  | 15  | 85  |

*Source*: Emmanuel (2012)

**Table 6. Typical classifications depending on separation practice.**

Efforts to prevent the inclusion of mercury in waste inputs will help to reduce overall mercury emissions form incineration. Measures to exclude mercury from waste inputs are therefore of special importance. These could be include such measures as the separate collection systems or proper classification of waste at all stages before incineration, and the separation of waste at the facilities as a primary technique.

The separate collection of waste streams which could potentially be contaminated with high amounts of mercury, and the diversion of mercury containing waste to environmentally sound management facilities could lead to a significant reduction of the mercury content in the waste going to incineration. There could be separate collection for the following wastes:

* Mercury-containing batteries;
* Mercury-containing lamps;
* Electrical devices (switches and others) that contain mercury;
* Potentially contaminated waste from households and municipal institutions (old paint and varnish, insecticides, solvents, used laboratory chemicals from schools, etc.).
	+ - 1. **Waste inspection and characterization before incineration**

The following general practice for waste input and control should be considered when identifying the BAT for handling waste containing or contaminated with mercury. When establishing and maintaining quality controls over the waste input, according to the types of waste that may be received at the installation, it is important to establish process input limitations and identify key risks, and also to communicate with waste suppliers to improve incoming waste quality control.

A thorough knowledge of the characteristics and attributes of the incoming waste is essential. The characteristics of a particular waste stream may vary significantly from country to country and region to region. If certain wastes or waste constituents are considered inappropriate for incineration, such as waste included in Article 11 of the Convention, procedures should be in place for detecting and separating these materials in the waste stream or residues prior to incineration unless the waste is intended for thermal treatment to recover mercury as described in the technical guidance for the ESM of mercury waste issued by the Basel Convention. Inspection, sampling and analyses should be performed as a matter of routine. This is particularly true for hazardous wastes. It is vital that manifests and audit trails be maintained and kept updated. Table 7 illustrates some of the techniques applicable to the different types of waste.

**Table 7**

Examples of inspection techniques ([EC](#_ENREF_5) 2006)

| *Waste type* | *Techniques* | *Comments* |
| --- | --- | --- |
| Mixed municipal wastes | Visual inspection in bunkerSpot checking of individual deliveries by separate offloading Weighing the waste as deliveredPeriodic sampling and analysis for key properties or substances | Industrial and commercial loads may have elevated risks |
| Pretreated municipal wastes and refuse-derived fuels | Visual inspectionPeriodic sampling and analysis for key properties or substances |  |
| Hazardous wastes | Visual inspectionSampling and analysis of all bulk tankersRandom checking of drummed loadsUnpacking and checking of packaged loadsAssessment of combustion parametersBlending tests on liquid wastes prior to storageControl of flashpoint for wastes in the bunkerScreening of waste input for elemental composition, for example by EDXRFa | Extensive and effective procedures are particularly important for this sector. Plants receiving monostreams may be able to adopt more simplified procedures |
| Sewage sludges | Periodic sampling and analysis for key properties and substancesProcess control to adapt to sludge variation |  |

a EDXRF: energy dispersive X-ray fluorescence (spectrometer).

* + - 1. **Removal of non-combustibles at the incinerator**

The removal of both ferrous and non-ferrous metals on site is a common practice at municipal solid waste incinerators and helps to prevent these wastes, which may contain mercury as an impurity, from entering waste incineration.

* + - 1. **Proper handling and storage**

Proper handling, particularly of hazardous waste, is essential and appropriate sorting and segregation should be undertaken to enable safe processing.

Storage areas must be properly sealed with controlled drainage and weatherproofing. Fire detection and control systems for these areas should also be considered, along with adequate capacity to retain contaminated fire water onsite. Storage and handling areas should be designed to prevent the contamination of environmental media and to facilitate clean-up in the event of spills or leakage. Odours and release of volatile persistent organic pollutants to environmental media can be minimized by using bunker air for the combustion process.

* + - 1. **Minimizing storage times**

Although having a constant supply of waste is important for continuous operation and stable firing conditions in large municipal solid waste incinerators, the accumulation and storage of a given waste for a long period of time is undesirable. Minimizing the storage period will help prevent putrefaction and unwanted reactions, and the deterioration of containers and labelling. Managing deliveries and communicating with suppliers will help ensure that reasonable storage times (e.g., four to seven days for municipal solid waste) are not exceeded.

* + - 1. **Waste loading**

For facilities that accept heterogeneous municipal solid waste, proper mixing and loading of the feed hopper is critical. Loading-crane operators must have the experience and the appropriate vantage point to be able to select the appropriate mix of waste types to keep the incinerator performing at peak efficiency.

The approach to BEP for incinerating wastes containing or contaminated with mercury are captured under the following:

* Waste prevention before incineration;
* Incinerator operating and management practices;
* Post incineration operating and management practices.
	+ - 1. **Incinerator operating and management practices**

Proper operation is critical to achieving design parameters. In general, the manufacturer or designer of the equipment should provide a manual that discusses operating practices, including start-up procedures, shutdown procedures, normal operation, troubleshooting, maintenance procedures, recommended spare parts and others. Operators must be able accurately to predict the heating value and other attributes of the waste being combusted in order to ensure that the design parameters of the incinerator are being met. This can be done using the results from a feed monitoring programme of key contaminants and parameters where sampling and analysis frequencies and rigour would increase as feed variability increases. Detailed information may be found in subsections 2.2.3.1–2.2.3.5 above.

* + - 1. **Site selection of an incinerator plant**

The location of an incinerator can significantly affect dispersion of the plume from the chimney, which in turn affects ambient concentrations, deposition and exposures to workers and the community. In addition to addressing the physical factors affecting dispersion, siting must also address issues of permissions and ownership, access and convenience and take into account social, health and other environmental impacts. Best practice siting has the goal of finding a location for the incinerator that minimizes potential risks to public health and the environment (EPA 1997).

* + - 1. **Design**

Adequate plans, drawings and quality control are essential in the construction of incinerators. These must include dimensional drawings, tolerances, material lists and other preparatory studies Through such proper design and operation, incinerators should be able to achieve desired temperatures, residence times, and other conditions necessary to minimize the emission of mercury into the environment, avoid clinker formation and slagging of the ash (in the primary chamber), avoid refractory damage, and minimize fuel consumption.

* + - 1. **Regular facility inspections and maintenance**

Routine inspections by the operator and periodic inspections by the relevant authority of the furnace and air pollution control devices should be conducted to ensure system integrity and the proper performance of the incinerator and its components. Regardless of how well equipment is designed, wear and tear during normal use and poor operation and maintenance practices will lead to the deterioration of components, a resultant decrease in both combustion quality, an increase in emissions, and potential risks to the operator and public.

* + - 1. **Operator training**

Regular training of personnel is essential for good operation of waste incinerators. Proper operation of incinerators is necessary to minimize emissions and other risks. Only a trained and qualified operator should operate or supervise the incineration process. The operator must be on site while the incinerator is operating. Without proper training and management support, incinerators cannot achieve proper treatment and acceptable emissions.

* + 1. **Prevention of fire risks**

At waste incineration plants, fires in the waste bunker can cause significant pollution, e.g,, mercury and other heavy metals, hazardous organic compounds, etc., in the vicinity of the plant. To minimize the risk of such fires the following measures could be considered as BEP:

* Use of automatic fire detection systems in waste bunkers, e.g., infrared cameras
* Installation of redundant monitors in waste bunkers
* Use of automatic fire detection systems for fabric and static bed coke filters, e.g., temperature control, electrical and control rooms, and other identified risk areas, e.g., smoke alarms
* Automatic fire control systems, e.g., with inert gas. Such measures are applied in some cases, most commonly when storing flammable liquid waste but also in other risk areas
* Provision of sufficient amounts of [extinguishing](http://www.dict.cc/englisch-deutsch/extinguishing.html) [water](http://www.dict.cc/englisch-deutsch/water.html)
* Sufficient retaining of [extinguishing](http://www.dict.cc/englisch-deutsch/extinguishing.html) [water](http://www.dict.cc/englisch-deutsch/water.html)
* Sufficient flue openings for smoke and heat (closed at normal operating conditions)
* Sufficient openings in the bunker walls for an extinction charge in case of fire (closed at normal operating conditions)
* Option to circle the incineration plant for the fire service
1. **Mercury monitoring techniques**

General and cross-cutting aspects of testing, monitoring and reporting are discussed in the introductory chapter of this document. Specific aspects inherent to waste incineration processes will be discussed in the following section.

* 1. **Direct methods**

Direct mercury measurements can be carried out either continuously or discontinuously.

**Continuous emission monitoring systems (CEMS)**

The advantage of continuous monitoring is that it helps ensure the proper functioning of the flue gas treatment installation and the early detection of any change in the mercury content in the waste.

Despite measures to control or minimize the input of mercury in waste incineration plants, significant amounts of mercury are still occasionally able to pass through the waste bunker into the combustion and thus into the flue gas and therefore to vary the level of mercury emissions.

With the help of continuously operating mercury measuring devices, such contamination can be recognized and countermeasures initiated quickly as needed. Figure9 shows the variation within one year of mercury concentration in the clean gas of a waste incineration plant in Hamburg. Distinct peaks can be seen, in particular in the months of October and November.



**Figure 9 Mercury emission data of one line of a waste incineration plant in Hamburg in 2014**

In some countries, the majority of the waste incineration plants are equipped with continuous operating devices. If elevated levels of mercury are detected in the flue gas, countermeasures can be initiated. These include, for example, the following:

* Increasing the injected amount of sorbents into the flue gas stream;
* Use of sulfur-predoped activated carbon with an increased reduction efficiency for mercury;
* Adding bromine to the combustion to enhance the oxidation of mercury.

If very high level of mercury is detected in hot spots in the waste, these hot spots should be evacuated. In the event of elevated mercury levels in the flue gas cleaning system, cleaning of the flue gas to remove mercury should be considered.

When elevated emission levels are observed the facility operator should check the monitoring and operating systems to determine the cause and take corrective actions. The operator should also monitor inputs and inform the waste deliverers about the input monitoring. Such measures are found to be effective in most cases, and lead to a significant decline in the number of exceedances.

CEMS are sometimes used to sample the particulate laden gas stream before a particulate control device (see 3.3). That makes possible an immediate response, e.g., by injecting activated carbon or halogenated compounds.

**Stationary source measurement (impinger)**

The use of impinger methods for mercury monitoring in waste incineration plants has historically been the preferred option. Owing to the complexity and cost of this method, impinger sampling is carried out less frequently, often only quarterly or annually. Stationary source measurement by impinger of a proper function of the flue gas treatment installation is only possible during short sampling periods. The detection of mercury peaks in the flue gas is commonly not possible and, therefore, no countermeasures can be initiated. Impinger methods are not appropriate, however, for long sampling periods and in practice are limited to several hours.

**Sorbent trap systems**

Sorbent trap systems make possible surveillance of the proper functioning of the flue gas treatment installation after a sampling period. While sorbent trap systems do not provide real-time results, the data obtained can indicate the operating performance over the previous set time period. With this feedback loop approach, adjustments to the process can then be made as needed. Compared to the impinger methods, sorbent traps provide more stable mercury retention and a simpler sampling protocol. The simpler sampling protocol allows for unattended operation of the monitoring over extended periods, which is not possible with the impinger methods.

This system is not commonly used in the European Union, because there are no legal requirements for its use. It is possible that it is used in other regions of the world.

* 1. **Indirect methods**

**Mass balances**

Mass balances are extremely difficult to apply, owing to potentially high mercury variations in waste input and the extreme difficulty of reliably monitoring mercury levels in heterogeneous waste.

**Predictive emissions monitoring**

Predictive emissions monitoring (parametric monitoring) is not possible at waste incineration plants since there is no relation between other pollutants and mercury in the flue gas. Added to which, mercury content in furnace feedstocks can change significantly over short periods, depending on the concentration of the mercury in the waste.

**Emission factors**

For monitoring purposes, emission factors should not be used for determining mercury emissions from waste incineration plants, because of the variable mercury content in waste.

**Engineering estimates**

Engineering estimates are not an accurate method of mercury air emission monitoring for waste incineration plants.

* 1. **Most appropriate techniques for monitoring in the waste incineration sector**

Both continuous and discontinuous monitoring are considered to form part of BAT implementation.

Continuous measurements are suitable for various reasons. Notably, they enable:

* Monitoring of the proper functioning of the flue gas treatment installation;
* Prompt detection of changes in the mercury content in the waste;
* Detection of high concentrations of mercury due to improper input of contaminated waste.

Several countries already require continuous monitoring of mercury at their waste incineration installations. They consider techniques for continuous monitoring as BAT. The majority of countries conducting mercury monitoring use discontinuous monitoring, e.g., impinger sampling.

Only continuous monitoring ensures that elevated mercury levels in cleaned gas and raw gas are detected for effective control. In such cases a sorbent may be used, e.g., sulfur-doped activated carbon.

In particular for hazardous waste, medical waste, mixed commercial and municipal waste, and also for all other waste types (including illegal entries) when it cannot be guaranteed that they contain no mercury, continuous measurement of mercury may be the most effective method.

Discontinuous measurement methods are also applicable. Sorbent trap systems and stationary source testing (impinger) monitoring make possible surveillance of the proper functioning of the flue gas treatment installation during the sampling periods. With these discontinuous measurement methods, the detection of high mercury levels in the flue gas is unlikely and, therefore no countermeasures can be initiated.

Indirect methods, such as mass balances, predictive emission monitoring, emission factors and engineering estimates, are not useful as measurement methods for waste incineration plants.

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